New Technologies in Biofuel Production

Rod Bothast

USDA Outlook Forum

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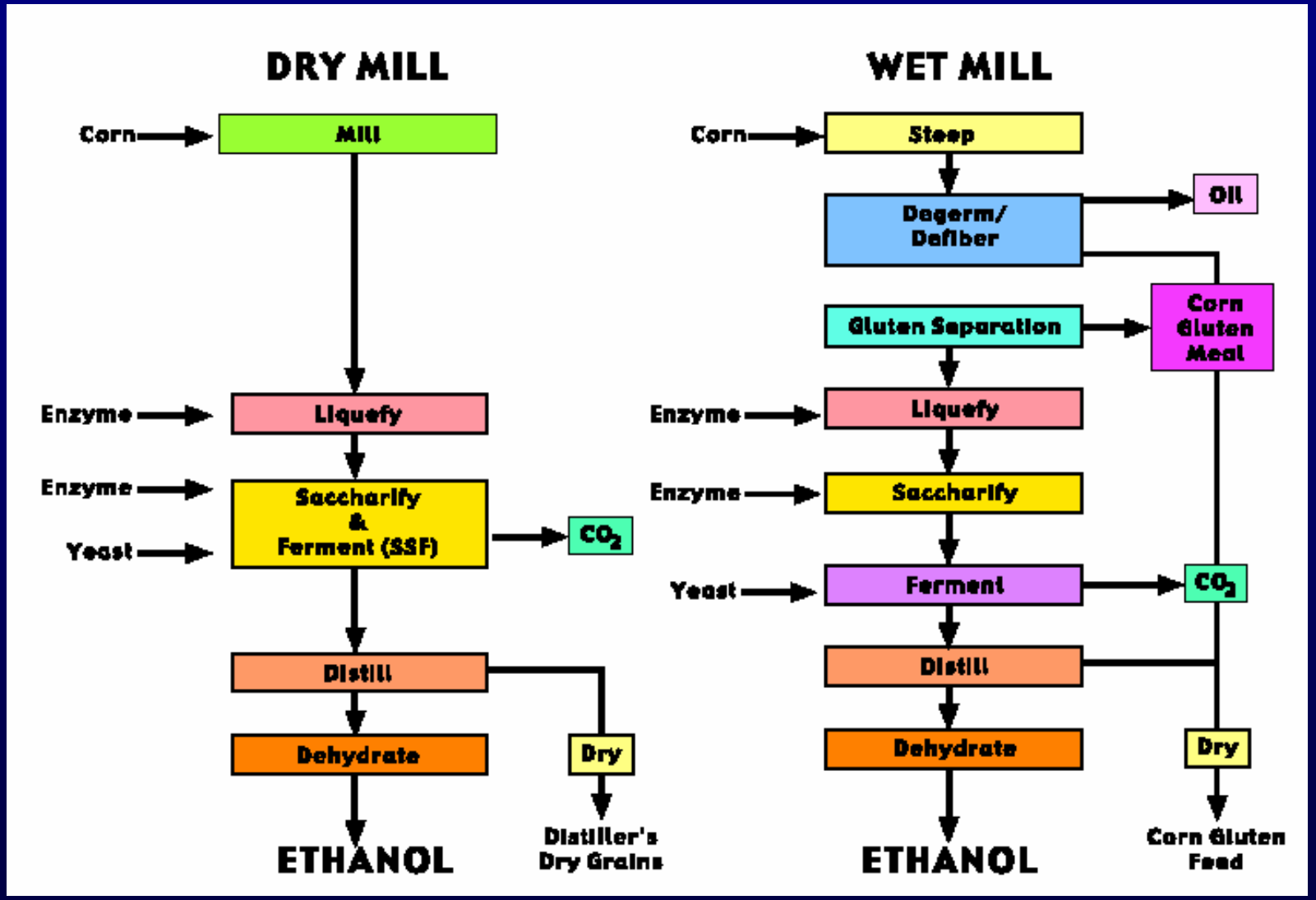
Current Ethanol Production Methods



Demonstrated Improvements

Corn Yields

Hybridization; annual yield improvements – 5 fold increase

Construction Costs – 55.5% cost reduction

Currently $1-$1.5/gallon

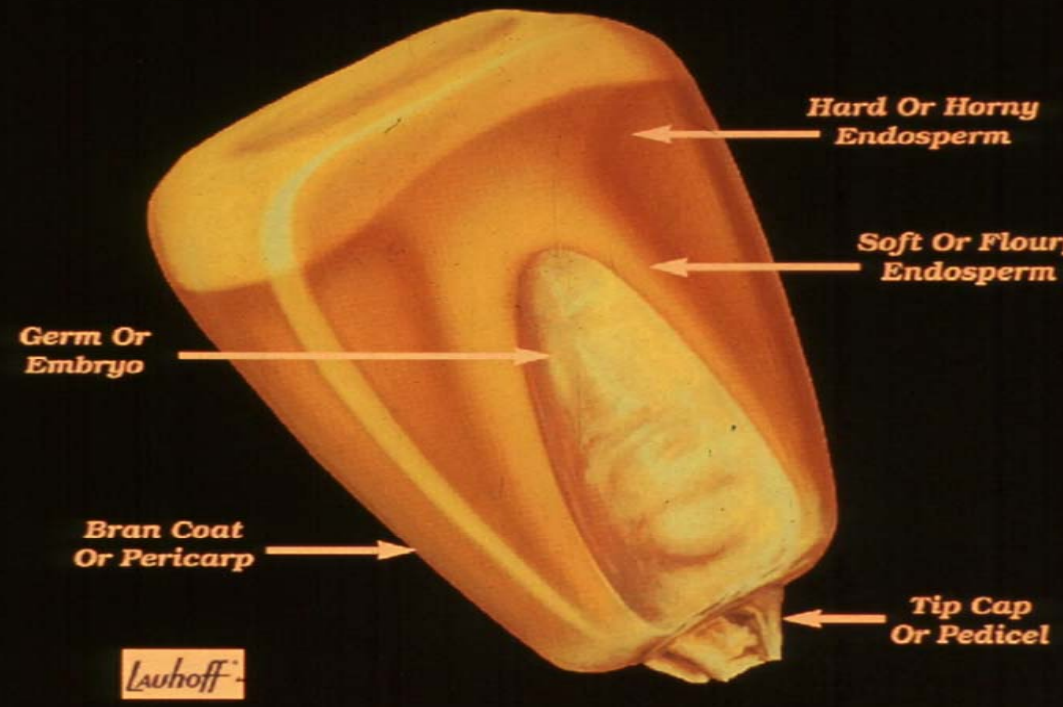
Net Energy Value - raised

from 22 to 67% (1995 to 2001)

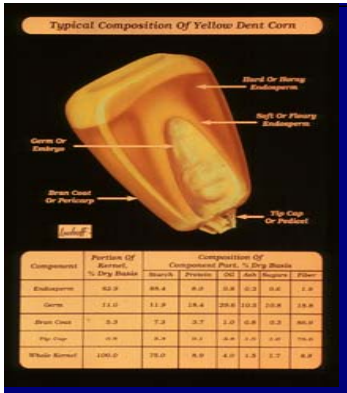
Process Efficiencies

2.7-2.8 gal/bu – dry grind process

Typical Composition Of Yellow Dent Corn



Component	Portion Of Kernel, % Dry Basis	Composition Of Component Part, % Dry Basis					
		Starch	Protein	Oil	Ash	Sugars	Fiber
Endosperm	82.9	88.4	8.0	0.8	0.3	0.6	1.9
Germ	11.0	11.9	18.4	29.6	10.5	10.8	18.8
Bran Coat	5.3	7.3	3.7	1.0	0.8	0.3	86.9
Tip Cap	0.8	5.3	9.1	3.8	1.6	1.6	78.6
Whole Kernel	100.0	75.0	8.9	4.0	1.5	1.7	8.9



Improving Hybrids for Dry-Grind Ethanol Production

- Numerous commercial hybrids now available
  - Pioneer(HTF), Monsanto(PPF), Syngenta(NKEE), Regional Seed Companies
- Ethanol yields increase from hybrid selection up to 4%
  - $1-2M annually for a 40mgy ethanol plant
- Extensive research has resulted in a better understanding of the complexity
  - Influenced by agronomic practices (plant population, applied nitrogen, etc), environment, hybrid selection and performance
- Self-processing grains
  - Starch hydrolyzing enzymes in transgenic corn kernels (Syngenta)

New and High Value Coproducts

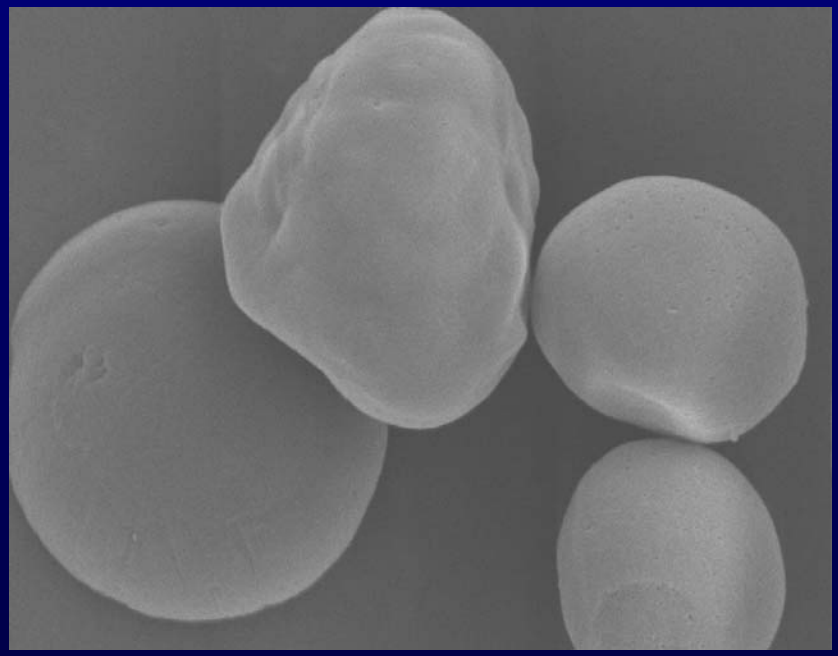
New processes

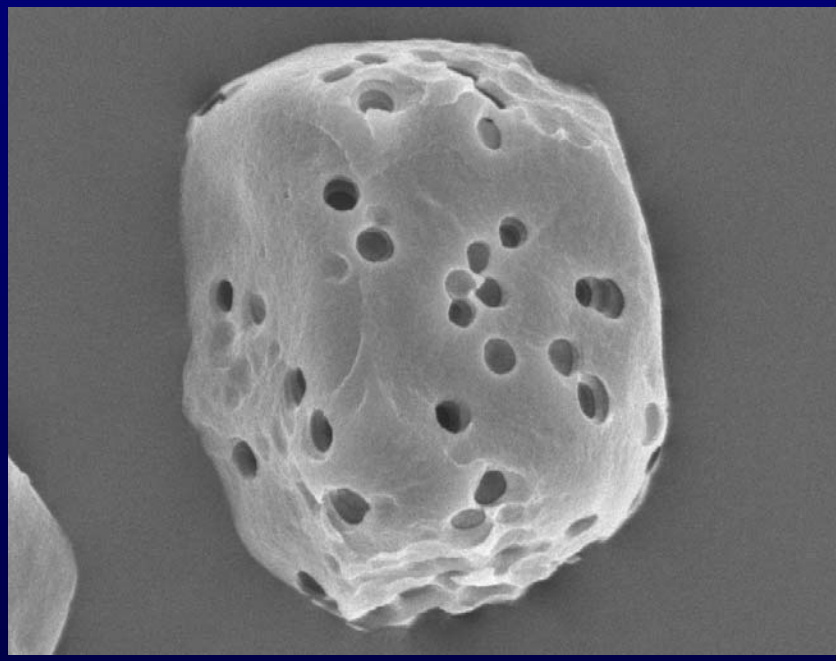
- QG, QGQF, Enzymatic milling, COPE,
- Modified DDGS with nutrient profile

Coproducts

- Corn oil, zein, fiber, corn fiber oil, sweeteners, polysaccharides, pharmaceuticals, nutraceuticals, biodegradable films, organic acids, solvents, amino acids, pigments, enzymes, polyols, vitamins, etc

Raw Starch Hydrolysis





From David Johnston, Cereal Chem. 79:523-527

Commercial Developments

ICM/ Genencor

Broin/ Novozymes(BPX)

- Direct conversion without a cook step
- Reduced energy input
- Reduced capital
- Increased yields
- Lower overall costs

US Biomass Sources

ECONOMICAL

Sugar Cane

Corn Starch

Corn Fiber

Paper

Switch Grass

Cottonwoods

Wood Chips

Stover

ABUNDANT & AVAILABLE

Corn Kernel Cellulosics

Near Term Technology Validation

- No incremental supply chain Costs
- Potential 14% Yield increase
- 4.5 M gal Ethanol per plant Annually
- Minimal incremental capital
- DDGS weight reduced 44%
- No increase in corn acres

Amounts of feedstocks to produce 10 ml ethanol

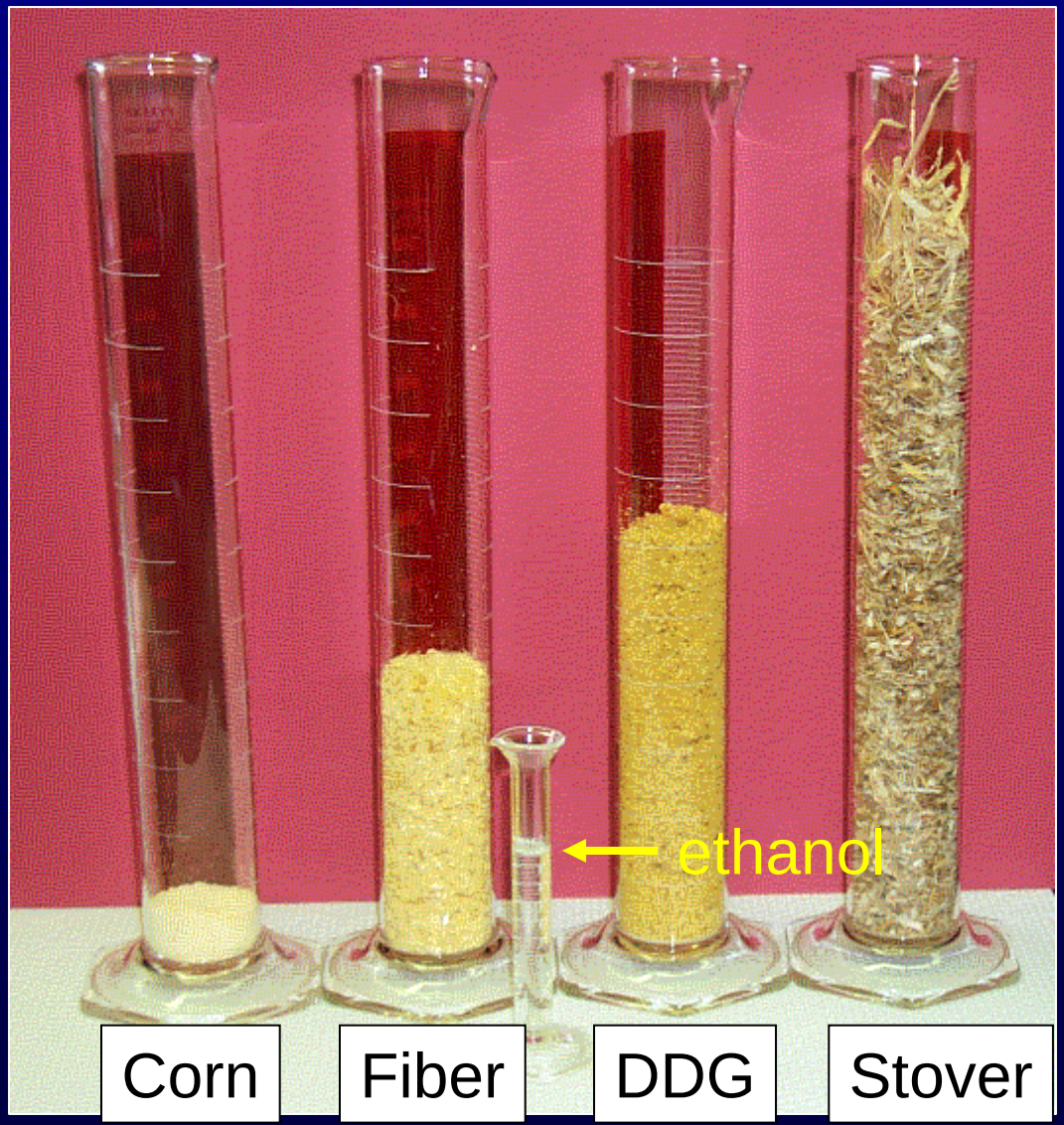
Moisture Content

Corn 15%

Fiber 46%

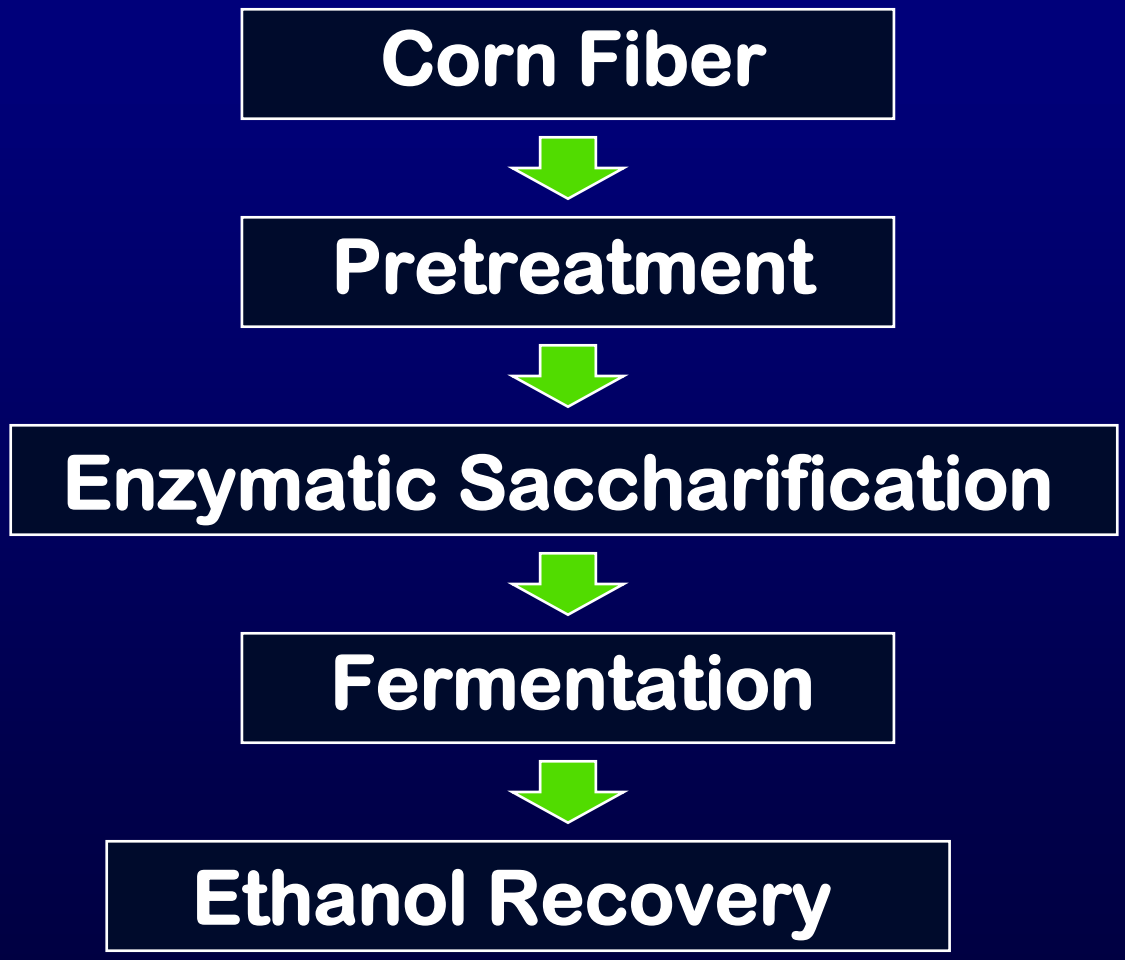
DDG 64%

Stover 5%

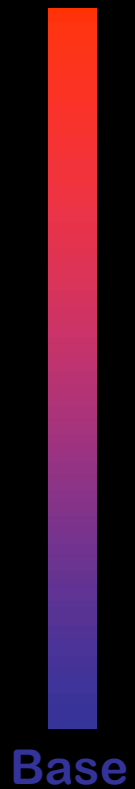


500 ml graduated cylinders used for comparisons

Utilization of Biomass for Production of Fuel Ethanol

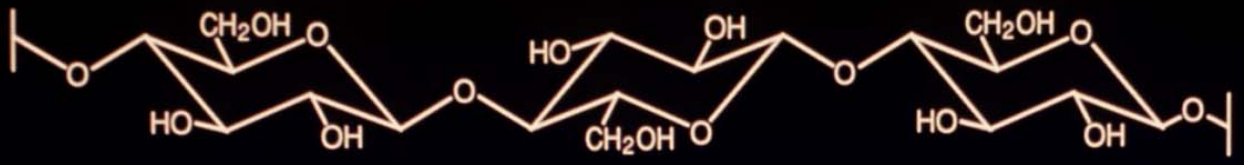


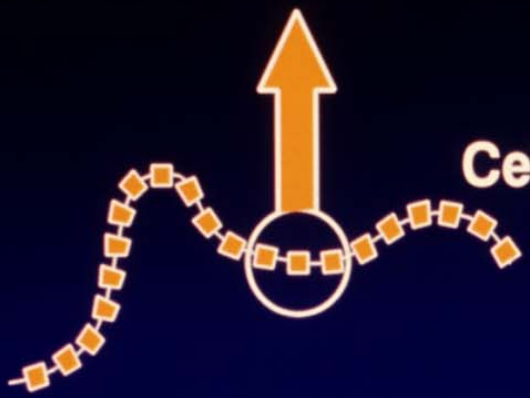
Selected Pretreatment Strategies



Pretreatment	Pentoses	Inhibitors
Strong Acid	+	++
Dilute Acid	+	++
Hot Water	-	+
AFEX	-	-
Alkaline Peroxide	-	-

Enzymatic Hydrolysis of Cellulose

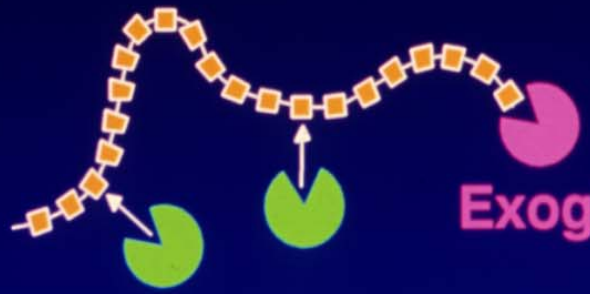




Inhibition

β-glucosidase → Glucose

and and



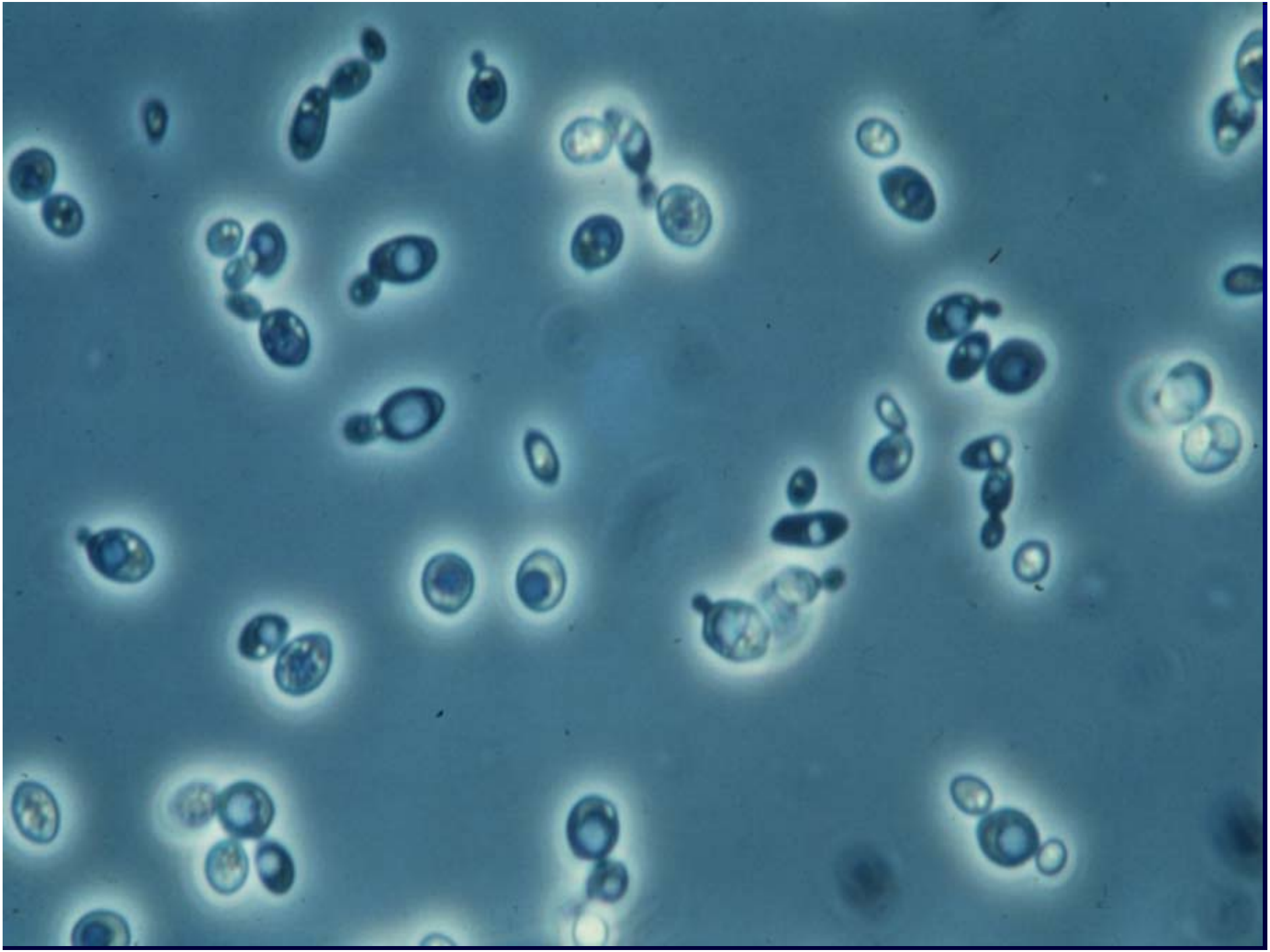
Glucose Cellobiose Cellodextrins

Exoglucanase

Endoglucanase

Inhibition

Inhibition



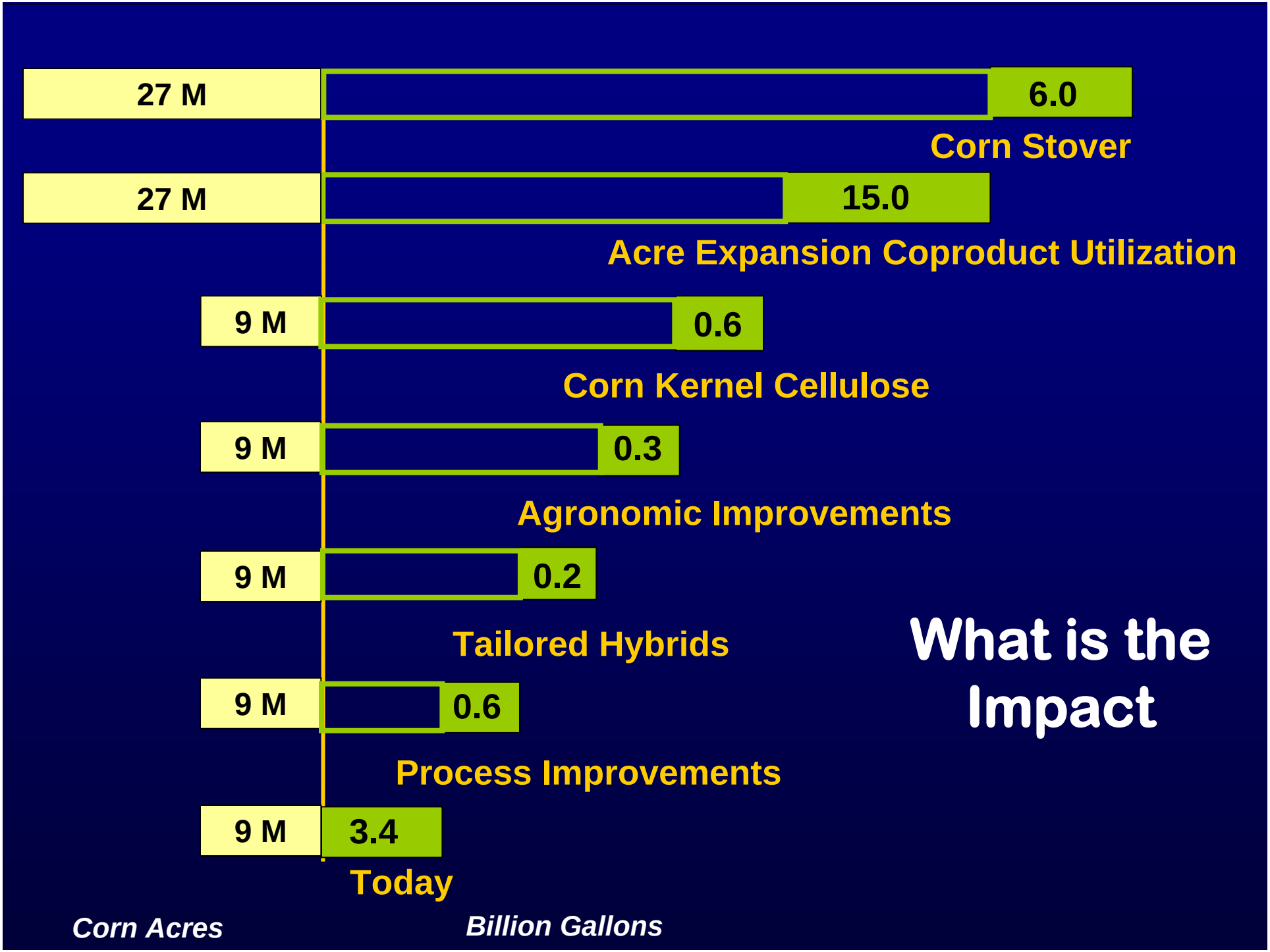
Recombinant Microorganisms for Fermentation of Mixed Sugars to Ethanol

- Recombinant organisms are now available
  - Recombinant *Escherichia coli*
  - Recombinant *Saccharomyces*
  - Recombinant *Zymomonas*
  - Recombinant *Klebsiella oxytoca*
- Commercialization prospects
  - BCI with recombinant *E. coli*
  - Iogen with recombinant *Saccharomyces*

Ethanol cost derived from $50/ton corn stover versus equivalent corn prices in dry-grind processing

	Conversion Rate Gallons Per Ton	Enzyme Cost Per Gallon	Cost Per Denatured Gallon	Corn Equivalent Prices
Future	89.7	$0.10	$1.25	2.35
		$0.25	$1.40	2.98
Base	68.0[b]	$0.10	$1.65	4.02
		$0.25	$1.79	4.62

From Tiffany and Eidman, 2004


27 M
6.0
Corn Stover
27 M
15.0
Acre Expansion Coproduct Utilization
9 M
0.6
Corn Kernel Cellulose
9 M
0.3
Agronomic Improvements
9 M
0.2
Tailored Hybrids
9 M
0.6
Process Improvements
9 M
3.4
Today
Corn Acres
Billion Gallons
What is the Impact